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Settling for colder homes as energy prices rise: evidence from 4200 households in Great Britain

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Abstract
2022 saw steep rises in energy prices in Great Britain. With gas space heating responsible for around half of domestic energy consumption, reducing home thermostat setpoints has the potential to significantly reduce demand and household energy bills.

The Smart Energy Research Lab (SERL) has been collecting smart meter and contextual data from around 13,000 GB households since 2018. In early 2023 SERL sent a survey to participants about their recent energy-saving behaviours along with dwelling and household information (including income and usual heating thermostat setpoint), receiving over 5,000 responses.

This paper presents a statistical analysis of how self-reported SERL participant temperature setpoints changed in winter 2022/23 compared with those they had reported previously. We analyse the variation in temperature settings with household (e.g. size, ages, income) and building (e.g. floor area, EPC rating) characteristics. We combine smart meter and financial circumstance data to identify those likely to be in fuel poverty and compare the thermostat setpoints of this group with the wider sample. We also investigate the characteristics of the households most likely to have reduced their setpoint.

The results show a significant reduction in reported thermostat setpoints in winter 2022/23 compared to winter 2020/21. The proportion of households reporting a setpoint lower than 18°C increased from 6.7% to 15.2%. While there are obvious energy efficiency benefits from thermostat reduction, the large share of households with temperatures lower than the recommended minimum highlights a concern for policy makers.

1 Introduction

This paper investigates heating temperature settings for a group of 4202 homes in Great Britain, and how these changed following steep energy price rises in 2022. Domestic heating is responsible for more than a quarter of UK energy demand (Ofgem, 2016). Reducing the temperature to which homes are heated has clear energy efficiency benefits (EST, 2022). However those aiming to influence heating behaviour are also conscious that too low an internal temperature could cause health problems. Temperatures below 18°C in living rooms in winter are not recommended (Public Health England, 2015) as these may cause or exacerbate medical conditions or lead to damp and mould.

The Smart Energy Research Lab (SERL) brings together half-hourly resolution household-level electricity and gas demand data with detailed socio-technical and weather data for a representative sample of over 13,000 households in Great Britain (Webborn et al., 2021). Participants completed a survey when they were recruited (between 2019 and 2021) which included a question about the usual temperature they set their heating controller (UKDS, 2023). This question should be set in the context of a typical British heating system. 90% of English homes have boiler systems with radiators and for 86% of homes the central heating is fuelled by gas (MHLC, 2021).

The sharp rise in energy prices which followed the Russian invasion of Ukraine in February 2022 brought public attention to potential for saving energy by reducing thermostat settings. Typical UK annual energy bills increased by 86% between winter 21/22 and winter 22/23 (DESNZ, 2023; Ofgem, 2021). Those struggling to afford rising energy bills sometimes had to choose whether to “heat or eat”; a shocking dilemma in 21st-century Britain highlighted by charities and in the media (Age UK, 2021; Viner, 2023).

A survey designed to investigate changes in energy using behaviours in this period of high prices was sent to SERL participants in January 2023. From answers received we can identify 4202 households which reported their heating temperature setting both in the recruitment survey and the 2023 follow-up survey. This paper analyses the trends in temperatures reported and the characteristics of those households most likely to reduce their setpoint.

We also investigate thermostat-setting behaviour linked to fuel poverty indicators. There are many ways in which Fuel Poverty can be measured (Moore, 2012; Siksnelyte-Butkiene et al., 2021; Thomson et al., 2017; Tirado Herrero, 2017). We use actual energy usage from the SERL observatory and calculate two metrics introduced by Waddams Price (2012) : Expenditure Fuel Poverty and Feeling Fuel Poor, explained further in Section 4.3. It was not possible to replicate British national fuel poverty definitions since these are not based on actual consumption, but derived from modelling the energy required to heat the home to a comfortable level (BEIS & BRE, 2020; DESNZ & BRE, 2023).

From the point of view of energy efficiency and emissions reduction, lower setpoints are beneficial. However this needs to be balanced with the potential negative effects of temperatures below the recommended level of 18°C (Public Health England, 2015), particularly on those who are vulnerable. Our interest in the changes in setpoint temperature leads to the following research questions:

1. How do heating temperature setpoints reported in early 2023 compare with those reported by the same household in the SERL recruitment survey (2019-2021)?

2. How do heating temperature setpoints reported in early 2023 vary with household and dwelling characteristics?
3. Which household/dwelling characteristics are associated with setpoint reductions?
4. Which household/dwelling characteristics are associated with setpoints below the recommended level of 18°C?

2 Method

2.1 Data sources

The SERL “recruitment survey” was completed by approximately 13,000 SERL participants who were recruited in September 2019, September 2020 and January 2021 (Webborn et al., 2021). This survey included the question “What temperature do you set your [heating] controller to in the winter months for the late afternoons or evenings?” Other questions asked about dwelling age and type (detached, semi-detached etc) (UKDS, 2023).

In order to investigate the impact of the large increase in energy prices seen in winter 202/23 the SERL Follow Up Survey 2023 was sent to 12,001 households in February 2023 and 5,829 responses were received. This survey included the question “During this winter, to what temperature do you set your heating controller for late afternoons or evenings?”. Other questions asked about household income and how difficult it was to meet heating costs.

4,202 participants provided temperature setting information in both surveys, and it is this sample which provides the basis for the analysis of changes in temperature settings over time. The SERL Observatory contains Energy Performance Certificate (EPC) information for those homes which have an EPC (approximately 60% of the Observatory homes). This was used to provide information about EPC rating and floor area for the analysis.

This contextual information from surveys and EPCs allows our sample to be compared with the general English building stock. There is a higher proportion of owner-occupied homes (90.3%) compared to 65.1% of homes in the 2021 English Housing Survey (EHS) (DLUHC, 2022). The age profile of the properties is similar (36.8 % before 1949 compares with EHS 34.9% before 1944). Table 1 below shows there are some differences in the distribution of EPC ratings, with a higher proportion in the E/F/G categories.

Table 1 Comparing sample EPC split with general English building stock (DLUHC, 2022)

EPC rating	% of sample with EPC	% of owner-occupied homes in England (DLUHC, 2022)
A or B	6.0%	2.9%
C	29.1%	40.0%
D	45.5%	46.8%
E	16.3%	7.8%
F or G	3.1%	2.5%

In addition to the contextual information from the surveys and EPC data, this study drew on the smart meter data available in SERL. Data for 2022 annual gas and electricity consumption for each home in the calculation of the fuel poverty indicator is described below.

2.2 Analysis

The data processing (using R version 4.1.2), was carried out in a secure computing environment provided by the UCL Data Safe Haven. The individual survey and smart meter data is confidential and participants are assured that no information that allows individual homes to be identified will be published. Statistical data control processes include the requirement for no statistics from groups of less than 10 homes to be divulged. Where data from small groups has been suppressed, this is noted in the captions.

The income data from the 2023 survey was combined with the annual energy consumption to provide an "Expenditure Fuel Poverty" (EFP) indicator of households spending more than 10% of their income and energy bills (Waddams Price et al., 2012). A number of assumptions were made for this calculation:

- The survey asked participants to choose an annual income band (e.g. £30,00 to £40,000). The band midpoint was used in the calculation (£105,000 for the "above £100,000" band).
- It was assumed that the energy tariff for all households was the same as the Energy Price Guarantee cap level for January-March 2023. This level, set by the government, varies by region and payment method (DESNZ, 2023). Some households may have more favourable tariffs from their suppliers but the UK trend was for all supplier to set prices at or extremely close to this cap level. This annual estimate clearly does not represent actual expenditure for a year in which variable tariff levels are changing at 3 or 6 month intervals. It assumes there is no change in energy demand between 2022 and 2023.
- The annual expenditure for gas and electricity was calculated based on the annual demand for the calendar year 2022 recorded by the smart meters. Costs for non-metered fuels (oil, LPG etc) were not available from SERL data and so were not included.

The binary variable FFP was used to indicate those households which answered "no" to the question "During the cold winter weather, can you normally keep comfortably warm in your living room?" and additionally respond that they gave this answer because they "you feel it is difficult to afford the fiel to heat your home" (this is the same combination of questions and answers to which Waddams Price (2012) originally gave the label "Feeling Fuel Poor").

A final indicator of a potentially fuel poor household, "struggling to pay", identified those respondents who answered "fairly difficult" or "very difficult" to the question "How easy or difficult is it for you to meet your heating/fuel costs?".

Comparisons of mean temperature setting and odds ratio for setpoint reduction were carried out for subsamples with particular characteristics, listed in Table 2 below. For binary characteristics the comparison was between those for which the condition was true or false. For categorical variables the category with the greatest number of households was taken as the reference case with which to compare the others.

The number of households in each of a set of categories does not necessarily add up to the total sample size of 4,202 as some data is missing. Questions which were answered "don't know" or "prefer not to say" were not included in the analysis.

Likelihood of reducing the thermostat was analysed in addition to mean setting, since different groups had different mean temperature settings in the recruitment survey, so a lower meant setting in 2023 does not necessarily imply a higher likelihood of reduction.

Table 2 Household and building characteristics tested for association with mean temperature setting / odds ratio for temperature reduction

	Class of characteristic	**Binary / categorical**
Number of occupants (reference 2)	Household	Categorical
Household member over 65	Household	Binary
Household member over 85	Household	Binary
Household member under 5	Household	Binary
Household annual income band (reference £20k-£30k)	Household	Categorical
Floor area band (reference 50-100m^2)	Building	Categorical
Dwelling type (reference detached)	Building	Categorical
Dwelling age (reference 1950-1975)	Building	Categorical
EPC rating (reference D)	Building	Categorical
EFP	Fuel poverty indicator	Binary
FFP	Fuel poverty indicator	Binary
Struggling to pay	Fuel poverty indicator	Binary

A binary variable "reduction" was set to true if the reported temperature in 2023 was lower than that in the previous survey, and false otherwise. The odds ratio (OR) for the likelihood of reduction for a particular category compared to the reference was calculated using the R epitools package (Aragon et al., 2020). This returned an odds ratio with upper and lower confidence limits (95%). The following explanation of the use of OR in an analysis of energy efficiency is based on that in Hamilton et al., (2014). The OR represents the odds of an outcome (e.g. reduction in setpoint) in a group, given a particular characteristic (e.g. household member under 5 years old) over the odds of not having that outcome given the same characteristic. If an outcome is associated with a characteristic the odds of exposure the OR is greater than one. If an outcome shows no association with a characteristic the odds will be the same in both groups (i.e. OR= 1). If an outcome is associated with a lack of a feature the OR is less than 1. Where the upper confidence level is >1 and the lower confidence level is <1 there is no evidence of significant association.

3 Results and discussion

3.1 Variation in setpoint temperatures

For the group of 4202 homes with settings reported in two surveys, the mean reported setpoint decreased from 20.2°C to 19.2°C. A t-test confirmed that the difference in means is significant ($p \ll 0.01$).

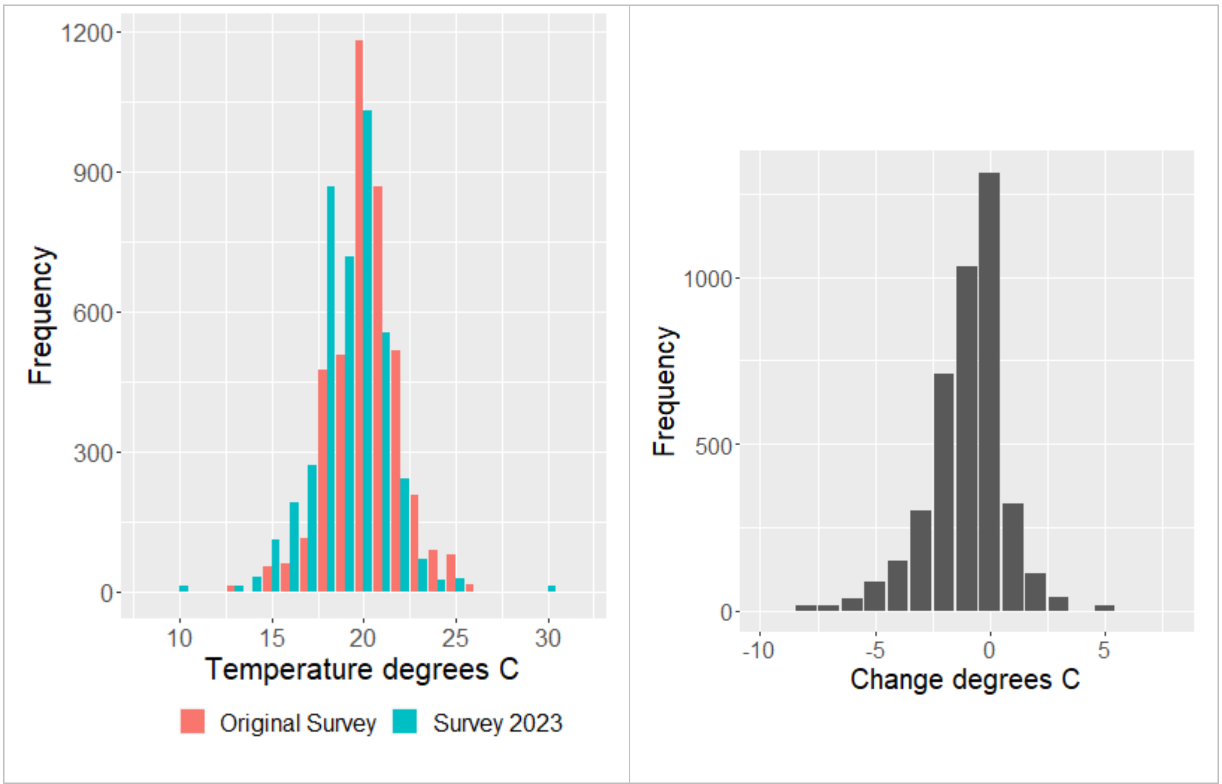
Table 3 shows mean and standard deviation of temperature setting for homes with reported setpoints the original survey by year of survey completion. This indicates that the 2023 decrease is a step change rather than the result of a gradual trend over time, since there was very little change in the mean between 2019 and 2021. In the analysis that follows all the recruitment survey results are grouped together rather than separated by date of recruitment survey.

Figure 1 shows histograms of the two survey setpoint results and of the difference between these. It can be seen that while the most common setting for both surveys is 20°C, a new peak

Table 3 Mean temperature setting reported by survey year

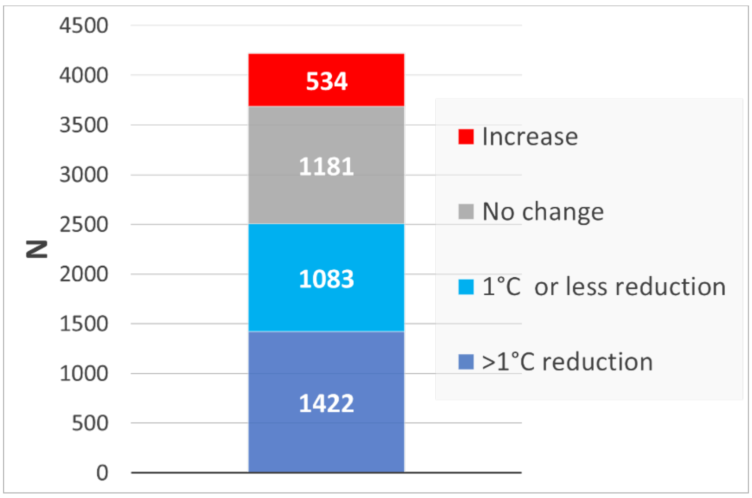
Recruitment survey year	N	Mean of reported thermostat temperature (°C)	Standard deviation of reported thermostat temperature (°C)
2019	1264	20.49	2.14
2020	2254	20.46	2.20
2021	6222	20.35	2.46
All recruitment surveys	9740	20.35	2.37
All 2023 survey (unmatched)	4947	19.21	2.28

Figure 1 Histogram of temperature setting and change between surveys (bars <10 suppressed)



Thermostat settings reported in 2 surveys	Change in setpoint

Figure 2 Level of reduction in temperature setting



at 18°C appears in the 2023 results. The proportion of homes with setpoints <18°C increases substantially (from 6.7% to 15.2%).

Figure 2 shows the sample divided by level of reduction (or increase). The largest group is those who reduced by over a degree. Around a quarter of the sample did not change their setting.

Table 4 shows mean setpoints from both surveys for subsamples grouped by characteristic. The results for t-test comparison of means are shown, with categories where there is a significant ($p<0.05$) difference in the mean setpoint highlighted in yellow. The percentage of setpoints in 2023 <18°C is also included.

Homes with a single occupant have a significantly lower mean setpoint than those for multi-person households. The <£10,000 annual income category has a lower mean temperature than the reference £20,000-£30,000 group and the highest income band (>£100,000) has a significantly higher mean. Over a quarter of the lowest income bands is reporting thermostat settings under 18°C, as are more than a fifth of those living in social rented housing.

Households with someone over 65 present have a higher setpoint than those which do not contain pensioners, and the difference is greater for households with a member over 85 years. No significant differences were seen for households with a child under 5.

The two oldest categories of homes are the only ones which show a significant (but small) difference in setpoint from the reference category (those built 1950 to 1975). The homes with floor area of 150-200m^2 had higher mean temperatures than the reference 20-100m^2 group. Homes with EPC A or B have a significantly higher setpoint than the reference category (EPC D). This could be because it is both easier and cheaper to maintain warmer temperatures in these well-insulated homes.

3.2 Characteristics of homes where setpoints were reduced

Table 4 shows the odds ratio for whether the group is more likely to reduce thermostat setpoint than the reference category. Those categories where there is confidence that the odds ratio is lower than 1 (upper confidence interval <1) are highlighted in blue; those where the odds ratio lower confidence interval is greater than 1 (i.e. more likely to reduce) are highlighted in green.

Households with members over 65 were less likely to reduce the thermostat setting than those without, but the presence of a child under 5 made no significant difference to the likelihood of reducing the setpoint. No significant differences are seen in reduction behaviour by income band or number of occupants.

There is a trend of higher likelihood of reduction as the age of the home decreases, but the only increase in the odds of temperature setpoint reduction that can be considered significant is for homes built between 1991 and 2002. Those with EPC E were more likely to reduce heating setpoint than those in the EPC D reference category. No other building characteristic showed a significant difference in odds of thermostat setpoint reduction.

Table 4 Statistics for subsamples grouped by characteristics. T_{2023} is mean setting reported in 2023 survey, ΔT is change in setting from that reported in recruitment survey

Characteristics	N	T_{2023}	ΔT	% < 18°C	t-value	p -value	Odds Ratio		
							value	95% CI	5% CI
Household characteristics									
Household member over 65	2343	19.34	-0.97	13%	4.76	0.000	0.82	0.93	0.72
Household member over 85	198	19.67	-0.87	13%	2.93	0.003	0.67	0.90	0.51
Household member under 5	2343	19.24	-1.01	15%	0.29	0.773	1.06	1.42	0.79
Size of household Reference 2 people	1846	19.33	-0.90	14%					
1 person	941	18.85	-1.24	20%	5.27	0.000	0.98	1.15	0.83
3 people	443	19.26	-0.95	14%	0.61	0.545	1.07	1.32	0.86
4 people	346	19.25	-0.97	12%	0.64	0.521	1.18	1.50	0.93
Household annual income Reference £20k-£30k	719	19.15	-1.11	15%					
Below £10k	139	18.56	-1.36	28%	2.04	0.043	0.90	1.31	0.62
£10k-£20k	641	19.00	-1.28	21%	1.13	0.260	0.92	1.14	0.74
£30k-£40k	591	19.29	-0.93	15%	-1.26	0.208	0.97	1.21	0.77
£40k-£50k	483	19.28	-0.89	12%	-1.08	0.278	1.00	1.27	0.79
£50k-£60k	315	19.19	-0.93	15%	-0.30	0.761	1.00	1.31	0.76
£60k-£70k	230	19.15	-1.12	17%	-0.01	0.993	1.17	1.59	0.86
£70k-£80k	157	19.36	-0.85	11%	-1.26	0.208	1.10	1.58	0.78
£80k-£90k	139	19.12	-1.05	15%	0.16	0.875	0.95	1.39	0.66
£90k-£100k	127	19.31	-0.91	9%	-0.99	0.321	0.92	1.36	0.63
>£100k	339	19.45	-0.79	9%	-2.43	0.015	0.78	1.02	0.60
Building characteristics									
Floor area band Reference 50-100m^2	1065	19.12	-1.06	18%					
<50m^2	121	19.51	-1.27	15%	-1.51	0.133	1.16	1.71	0.79
100-150m^2	603	19.13	-0.92	15%	-0.12	0.904	0.98	1.21	0.80
150-200m^2	199	19.39	-0.89	11%	-1.89	0.059	0.91	1.24	0.66
>200m^2	117	19.25	-0.93	13%	-0.75	0.455	1.02	1.51	0.69
Dwelling type	1627	19.20	-0.97	14%					
Semi-detached	1285	19.16	-1.12	16%	0.53	0.596	1.09	1.27	0.94
Terraced	891	19.07	-0.97	16%	1.55	0.122	1.02	1.21	0.87
Dwelling age Reference 1950 to 1976	1162	19.31	-0.96	15%					
Before 1900	436	19.01	-0.97	16%	2.58	0.010	0.87	1.09	0.69
1900 to 1929	491	19.02	-0.86	17%	2.55	0.011	0.95	1.17	0.76
1930 to 1949	583	19.11	-1.13	15%	1.68	0.094	0.88	1.08	0.72
1976 to 1990	624	19.21	-0.99	15%	0.96	0.337	1.12	1.36	0.92
1991 to 2002	469	19.16	-1.17	16%	1.28	0.202	1.34	1.68	1.08
2003 onwards	343	19.46	-1.04	13%	-1.12	0.265	1.07	1.37	0.84
EPC rating Reference D	958	19.11	-0.96	17%					
A or B	128	19.81	-1.11	13%	-3.64	0.000	1.06	1.54	0.73
C	613	19.28	-1.01	14%	-1.51	0.130	1.04	1.27	0.84
E	342	18.99	-1.16	18%	0.92	0.359	1.30	1.68	1.01
F or G	64	19.05	-0.77	14%	0.19	0.850	0.91	1.53	0.55
Fuel poverty indicators									
EFP	401	19.15	-1.21	18%	2.39	0.144	2.39	2.93	1.95
FFP	276	18.24	-1.93	34%	2.20	0.139	2.20	2.93	1.67
Struggling to pay	570	18.91	-1.52	24%	1.47	0.138	1.47	1.77	1.22

3.3 Households likely to be in fuel poverty

Those households identified as “expenditure fuel poor” (EFP) were significantly more likely to have reduced their temperature setting in 2023 (OR 2.39) however the mean setpoint temperature for this group was not significantly different to the rest of the survey sample. This can be explained by observing that this group reported a slightly higher setpoint than those not in EFP in the original survey.

The group which reported that they could not afford to keep their living room comfortably warm (FFP) also had high odds for reduction and a very low mean setpoint reported in 2023 (18.24°C) with a mean reduction of 1.93°C. 34% of this group reported potentially harmful setpoints of less than 18°C.

The “struggling to pay” group (who said it was fairly or very difficult to meet their energy costs) also had a low mean setpoint temperature and high odds of reduction, but not to the same extent at the smaller FFP group.

3.4 Limitations

This analysis has focused on reported evening temperature setpoints. There are a number of reasons why the actual temperature experienced by the household may differ from the setpoint number reported by the respondent:

- The household may vary the setpoint frequently or the survey respondent may not recall the setpoint accurately. However Smart Systems and Heat (2014) reported good agreement between reported settings and those observed by a surveyor in 2,287 homes.
- The setpoint may not be reached. A typical heating pattern in British homes is to run the heating intermittently, often for a short period in the morning and a longer period in the evening (Huebner et al., 2015; Rudge, 2012). Measurements of temperature in homes have shown considerable variation in temperature over the day and from day to day, with the temperature in some homes never appearing to reach a plateau that would indicate that the setpoint temperature had been reached (Huebner et al., 2013, 2015). The thermostat temperature should not be equated with the mean internal temperature, but considered as the maximum likely to be achieved at some point in the day.
- In many British homes the heating is controlled by a single wall-mounted thermostat in the hallway; the temperature at this location may differ significantly from the temperature in the living room or other areas of the house.

Despite these uncertainties, Few and Oreszczyn (2022) found a clear trend in energy demand reduction for each 1℃ decrease in reported thermostat temperature between 22℃ and 18°C in a typically sized house.

The indicators of fuel poverty used in this study do not match the current “Low Income, Low Energy Efficiency” definition for England (DESNZ & BRE, 2023) or the different definitions used in other UK nations (Office for National Statistics, 2023). These national measures are based on a model calculation of energy to achieve comfortable temperatures rather than the actual energy used.

4 Conclusions

There was a significant reduction in reported temperature settings between 2021 and 2023 (in contrast to the small changes recorded between 2019 and 2021). This strongly suggests that the increase in energy prices in 2022 and associated attention given to energy efficiency led to a large number of UK households reducing their heating setpoint. Homes with a pensioner present were less likely to reduce temperatures, as might be expected given the vulnerability of this group. No difference was seen for homes with young children. The strongest demographic associations with a lower setpoint were for households with an annual income under £10,000 and single-person households.

The physical characteristics of a building were not associated with large differences in setpoint. The oldest homes (built before 1929) have a slightly lower mean setpoint and this, combined with higher temperatures in homes with EPC A or B, suggests that those in modern, well insulted homes are likely to keep these at (slightly) warmer temperatures on average.

While the relatively small groups of those indicated in being in fuel poverty did not show significant differences in mean thermostat settings, there is strong evidence of greater setpoint reductions by those spending more than 10% of household income on energy and those reporting that they could not afford to heat their living room to a comfortable temperature. Overall, one sixth of the survey group reported setpoints lower than the recommended minimum of 18°C. The large increase in this proportion from the earlier survey is a cause for concern.

Policymakers must balance encouraging energy efficiency with ensuring that the basic needs for heating in wintertime are met. There are few clear trends associating particular dwelling characteristics with low temperature setpoints, but it is clear that low income and single-person households have disproportionately low mean setpoints. These groups should be supported to make heating more affordable. On the other hand, there is scope to encourage further setpoint reduction in high-income households without vulnerable members.

This study highlights the benefits of a large-scale, longitudinal data-gathering project such as SERL which allows researchers to track changes in energy using behaviour and the impact on energy consumption. Further work is underway to investigate the correlation between reported temperature setting reductions and reduction in winter energy demand (taking into account the properties of individual buildings). Future work will explore alternative indicators of fuel poverty using smart meter data in more depth.

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